Power Quality Improvement Using Unified Power Quality Conditioner

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
in
ELECTRICAL ENGINEERING

BY

Shrutisnata Mishra

Roll no: 214EE4248

Power Electronics and Drives

DEPARTMENT OF ELECTRICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA
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Under the Supervision of

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Certificate

This is to certify that the thesis entitled, "***POWER QUALITY IMPROVEMENT USING UNIFIED POWER QUALITY CONDITIONER***" submitted by **Shrutisnata Mishra** for partial fulfilment of the requirements for the award of Master of Technology Degree in Electrical Engineering with specialization in **Power Electronics and Drives** during 2015 - 2016 at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Place: NIT Rourkela

Date: May, 2016

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ABSTRACT

Power quality can be defined as any power problem faced in the frequency, current or voltage deviation which leads to mal-operation of the customer's equipment. It has been always difficult to maintain the quality of electric power so as to keep it within the acceptable limits. Mainly the use of power electronics devices that acts as the nonlinear load is responsible for the degradation in the poor power quality. Poor power quality results in various problems in the distribution systems like higher power losses, harmonics, sag and swells in the voltage, poor distortion and displacement factor. The recent developments in communications, digital electronics, and control system have rapidly increased the number of sensitive loads that require ideal sinusoidal supply voltage for their proper operation. So it became necessary to include some sort of compensation in order to meet limits proposed by standards. Here Unified power quality Conditioner (UPQC) has been used to overcome the power quality problem. UPQC which is a combination of back to back connected series and shunt APFs through a common DC link voltage, the two APFs function differently. The shunt active filter is mainly advantageous in removing the current related problems and the improvement of power factor and regulation of DC link voltage. Whereas the series APF helps in correction of voltage related problems by acting as a controlled voltage source. The voltage that is injected in series with the load by series Active Power filter is made to follow a control law which results in a sinusoidal load voltage that is the sum of the voltage injected by the series inverter and the input voltage. Whereas the shunt APF acts as a current source that injects a compensating harmonic current in order to have sinusoidal, in-phase input current. Several control strategies has been reported in literature that determines the reference values of the voltage and the current. Two control strategies has been described here i.e. the UVTG (unit vector template generation) and the synchronous reference frame, P-Q technique. UVTG is used for the control of both series and shunt active power filter whereas in the other method synchronous reference frame method is used for the control of SAF and the P-Q method is used for the control of shunt APF. UPQC has the capability of compensating the harmonic current, reactive power, voltage imbalance and voltage sag and swell. It also helps in reducing the energy losses that happens in the power systems element and also increases the operation safety.

CONTENT

LIST OF FIGURES

LIST OF ABBREVIATIONS

MOSFET	Metal oxide semiconductor field effect transistor
BJT	Bipolar junction transistor
SCR	Silicon controlled rectifier
IGBT	Insulated gate bipolar transistor
UPQC	Unified Power Quality Conditioner
APF	Active Power Filter
THD	Total harmonic voltage distortion
TDD	Total demand distortion
PCC	Point of common coupling
MPC	Model predictive controller
PI	Proportional integral
UVTG	unit vector template generation
PAC	power angle control
FACTS	Flexible AC transmission systems
TSC	Thyristor switched capacitor
TSR	Thyristor switched reactor
SVC	Static VAR compensators
D-STATCOM	Distribution Static Compensator
DVR	Dynamic voltage restorer
VSI	Voltage-source inverter

CSI	Current-source inverter
PWM	Pulse width modulation
LPF	Low-pass filter
MLI	Multilevel inverter
SAF	Series Active Filter
FFT	Fast Fourier Transform

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Power quality mainly deals with the interaction among the customers and the utility or it can be also said that it provides an interaction between the power system and the respective load. The ultimate goal of power system is the supply of electric energy to its customers. In the last 50 years or so, because of the extensive growth of industries electricity demand has tremendously increased which has led to establishment of many power generation and distribution grid. The demand for large amount of power for industrial and domestic use increased the burden on the generation. Electrical utilities working today are working as a subsystem of a large utility network that are tied together in order to form a complex grid. All these factors have put the power system under the requirement of a power quality. A high power quality is the main aim of the commercial facility design, along with "wellbeing," "trustable service" and "low beginning and working expenses". Problem in power quality is usually referred to any electrical problem faced in the frequency, voltage or current deviation which leads to mal-operation of the customer's equipment. Often when we talk of quality of power we actually mean the quality of voltage because it is the voltage which is controlled most of the times. The term power quality can be related with reliability of the system by the electrical utilities. The most difficult thing is maintenance of the electrical power quality so that it will lie within the acceptable limits. There are many disadvantages of poor and low power quality. It may lead to higher power losses, abnormal and unusual behaviour of electrical equipment, and interference with the nearby communication lines, poor voltage profile, harmonics, sag and swells in the voltage, poor and low distortion and displacement factor.

In the recent era power electronic and electronic equipment are becoming more and more sensitive as compared to their counterparts few years back. The equipment which is very much susceptible to this variation or degradation of power quality is the sensitive loads. Pure sinusoidal voltage is required for its proper operation. Along with the increased sensitiveness of the equipment, the growing sensitiveness of companies towards the production loss on account of reduction in the margin of profit has also added to the burden on the quality of power. From ages electricity has been considered as a basic right in the domestic life and it will always be there. Due to this very reason even a small interruption in the supply leads to heavy complaints, even if no damages are related to it.

Tripping of the electrical equipment because of aggravations in the supply voltage is frequently portrayed by clients as "awful power quality". On the other hand utilities frequently see unsettling influences because of the end client equipment as the principle power quality issue. The trouble in evaluating power quality concerns is clarified by the way of interaction among the quality of power and the equipment. What is "great" power quality for one equipment could be "awful" power for another. Two indistinguishable equipment may respond diversely to the same power quality parameters because of contrasts in their assembling. Modern electronic equipment is not only responsible for voltage unsettling influences; it additionally causes aggravations for different consumers. The main culprit behind this poor power quality is the use of power electronic devices that are mainly the equipment driven by converters and rectifiers like computer, speed drives etc. that acts as non-linear load. The increased use of power electronic devices has increased the tension on power system as it leads to generation of voltage and current harmonics and it also increases the reactive current. Nowadays, power electronic devices are used by the industries for many reasons like variable voltage, variable frequency and current control in order to get accurate controllability, better and higher efficiency, faster response and most importantly to make the devices compact in size. They have prompted an expansive development of voltage unsettling influences, albeit luckily not yet to a level where equipment gets to be sensitive. The fundamental problem here is the non-sinusoidal current of rectifiers and inverters that not only contain the fundamental component but also the harmonic components. The main problem arises because of the switching actions which these power electronics devices exhibit such as MOSFET, BJT, SCR, IGBT etc. Because of this switching action these devices acts as non-linear loads. The displacement and distortion factors also become poor as these devices draw leading/lagging and non-sinusoidal current from the supply, thereby resulting in injection of harmonics in the distribution systems. The harmonic current then starts flowing across the line and source impedance and this causes distortion of voltages, excessive power loss and voltage drop.

As the supply voltage gets distorted it leads to mal-operation of protection, control, and the metering equipment. So the necessity for maintenance of the power quality standards arises and to achieve a voltage that will be purely sinusoidal, the use of compensation technique is very much important. Many consumers are also there whose need of power quality is high than what provided by the electrical networks. So it’s very much essential to obtain a higher quality of electrical power.

Custom power devices and FACTS devices are used widely in order to overcome these problems and in order to assure a high and better power quality. Custom power devices refer to the power electronic controllers used in the distribution systems to get a higher level of power quality. They act as power conditioning equipment that helps in mitigating the distorted voltage and current. DVR, DSTATCOM, active filters etc. are utilized as a part of request to enhance the quality of voltage and current to a better standard.

Unified Power Quality Conditioner (UPQC) is a very effective step in improving these power quality problems. It is a combination of parallel-Active Power Filter and Series-Active power Filter. Both of these filters are associated through the same dc link. Parallel active filter is connected parallel with the load. It helps in compensating the harmonic current flowing through the load, compensates reactive power demand of the load and helps in maintenance of a constant dc link voltage. On the other hand, series active power filter is connected in series with the utility voltage by the help of series transformer and helps in maintenance of a sinusoidal the load voltage. So as a whole it helps in a simultaneous compensation of the delivered load voltage and source side currents.

1.2 DEFINATION OF POWER QUALITY

A consistent amplitude and one constant frequency sinusoidal signal is considered as an ideal current or voltage signal. Quality of voltage taken from the utility or that delivered to the consumer is referred as voltage or current quality. The fluctuation of voltage, current or frequency from its optimal worth that may prompt mal-operation of the equipment can be considered as issue in the power quality. The term electromagnetic compatibility is also used in place of power quality, they are strongly related but not the exactly same.

As indicated by the IEEE principles, Power quality can be characterized as the technique for grounding and supplying sensitive equipment with power so as to get a reasonable and agreeable performance of the equipment .Overall power quality represents a blend of quality of the current and voltage. Voltage quality at the point of connection is governed by the network operator whereas the quality of current at the connection point is governed by the client's load.

Taking into account the prerequisites power quality can have various different meanings and significances. In the view of manufacturer, the term power quality can be characterized as the way in which there ought to be no voltage variety and no noise generation in the system of grounding. In context of utility designer, it can be considered as voltage availability. Whereas for the end users power quality can be considered as the feasibility of utilising the accessible power for operation of various kinds of loads. Distribution system is worst affected because of the power quality problems. Power quality becomes poor at the points where loads are connected with the distribution system. So here we’ll try to upgrade the quality of power of the distribution system.

1.3 NEED OF BETTER POWER QUALITY

Power quality is becoming an important concern because of many reasons. Some major reasons are-

- To increase the efficiency of power system many new devices such as shunt capacitors and adjustable-speed motor drives are gaining popularity. These devices increase the harmonic level of the power system which increases the concern.
- Power electronic devices and loads that make use of control based on microprocessor and microcontroller based are more affected by power quality issues.

- The interconnected networks that are used nowadays are badly affected by the power system disturbances because if any component is failed the entire system is affected.
- The awareness of problems in the quality of power and difficulties faced like under voltage, overvoltage, flickers etc. is among the utility customers or end users is tremendously increasing which arises the demand of a high and better quality of power.

1.4 COMMON DISTURBANCES IN POWER SYSTEM

1.4.1-Short Duration Voltage Variation

The duration of Short Duration Voltage Variation is very less i.e. less than 1min.The main reason for this are-large load energisation, fault conditions etc. Short duration voltage variation includes Voltage sag, voltage swell and interruption.

1.4.1.1-Voltage Swell:

It's the increase in the line-voltage (rms) to 1.1-1.8% of the nominal line-voltage for a small period of half cycle to 1 min. Main cause for this is Swells can be switching off of a large load.

1.4.1.2-Voltage Sag:

It's a decrease in the line voltage (rms) to 10 to 90 % of the standard line-voltage for a period of half cycle to a min. It is also referred as "dip". The main cause for this voltage sag is starting of large induction motors.

1.4.1.3-Interruption:

It's the reduction in current or line-voltage to a value which is less than 0.1 pu for a duration not more than 1 min. Main causes for this are failure of equipment, faults etc.

1.4.2-LONG-DURATION VOLTAGE VARIATION

1.4.2.1-Under Voltage:

A reduction in the root mean square ac voltage to a value less than even 90 %. Its span is little more than a min. The main reason for this overvoltage is switching off of the capacitor bank.

1.4.2.2-Overvoltage:

It's a rise in the root mean square ac voltage to a value more than 110 %. Its san is also greater than a min. Main cause for this overvoltage are load switching.

1.4.2.3-Sustained Interruptions:

It is the situation when supply voltage is zero for a timeframe surpassing a minute.

1.4.3- VOLTAGE FLUCTUATIONS

It's a comparatively very small variation in the line voltage (rms).The variation is even less than 5%.The main culprits for this are arc furnaces, Cycloconverters etc. This is also referred as "flicker".

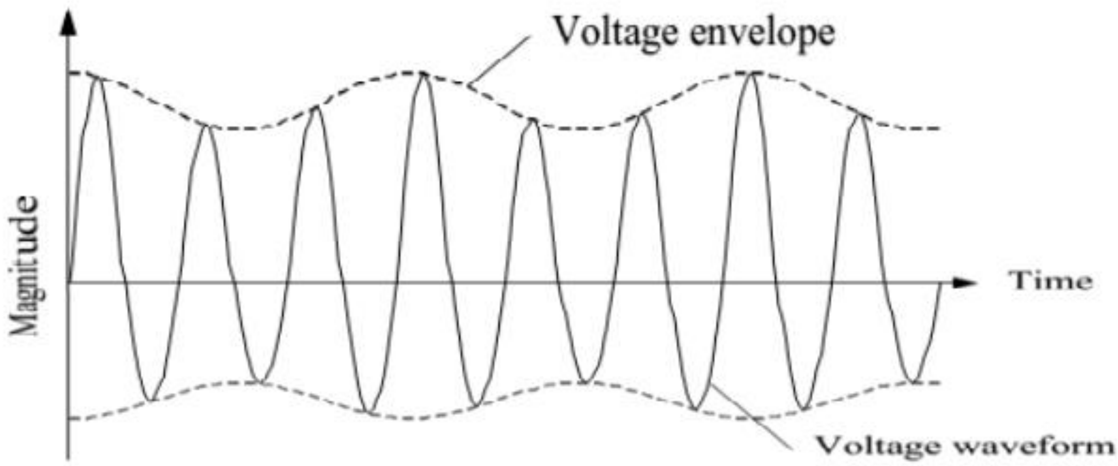


Figure 1.1 Voltage fluctuation

1.4.4-VOLTAGE UNBALANCE

It’s the amplitude variation of the phase voltages, regarding each other. This voltage unbalance is essentially because of various loads on the phases.

1.4.5-TRANSIENTS

1.4.5.1-Impulsive Transient:

It’s the unidirectional change in current or voltage on a power line. The main reasons for this are inductive load switching and lightning strikes.

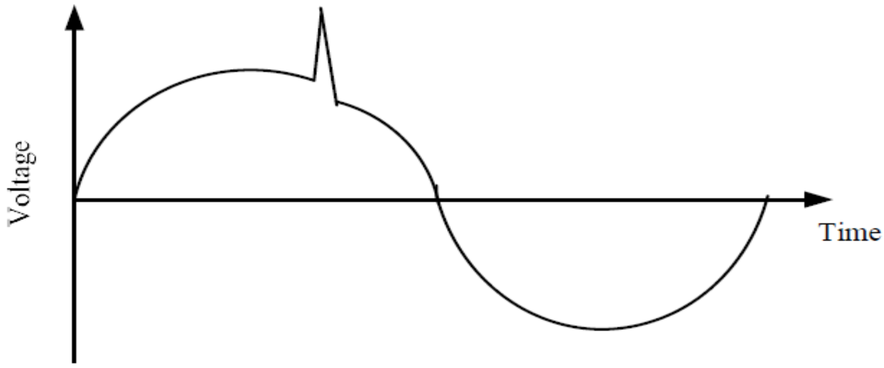


Figure 1.2 Impulsive transient

1.4.5.2- Oscillatory Transient:

It’s a bidirectional change in current, voltage on a power line. The main reason for this is the switching of capacitors for power factor corrections.

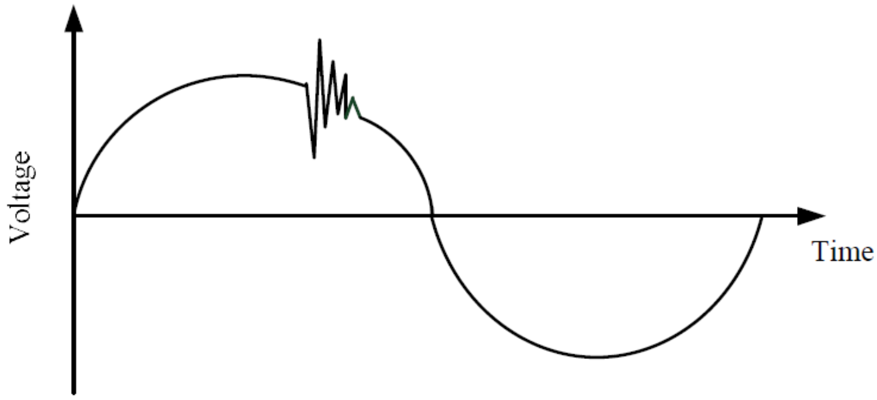


Figure 1.3 Oscillatory transient

1.4.6-WAVEFORM DISTORTION

It's mainly the variation from the sine wave of power frequency. It can be of various types as mentioned below-

1.4.6.1-Harmonics:

While supplying of a nonlinear load from a supply voltage at the power frequency, thee nonlinear load draws currents at more than a particular frequency that finally leads to a distorted current waveform. These are current or voltage signals having frequencies in terms of integral multiples of fundamental frequency. Total harmonic voltage distortion (THD) is utilized for measurement of the level of harmonic present in any waveform. THD measures magnitude as well as phase of each individual harmonic component. The THD information may sometimes be misleading, so in order to overcome that another terminology has been introduced by the IEEE standards. It is known as the total demand distortion (TDD). TDD is similar to THD with the difference that the harmonics here are expressed as a percentage of some rated load current rather than a percentage of fundamental current.

1.4.6.2-Interharmonics:

These are current or voltages waveforms whose frequency components are not the integer multiple of the normal frequency (i.e.50 or 60 Hz).The sources for this inter-harmonics are arcing devices, cycloconverters etc. The impact of interharmonics is not that clear but it has been seen that they affect power line carrier signalling.

1.4.7-DC OFFSET:

DC offset is present in a system when a dc current or voltage is present in alternating current network. Asymmetry of power converters results in DC offset. DC offset has many ill effects e.g. they cause saturation of transformer which on the other hand increase the transformer losses and reduces the life of the transformer. Dc offset also affects the grounding electrode by causing its electrolytic erosion.

1.4.8-NOISE-

It mainly refers to the undesirable electrical signals those results in unwanted impacts in the control system circuit in which they happen. They are mainly the outcome of arcing devices, power electronic and control devices. The problem of noise can be overcome by the use of isolation transformer, filters etc.

1.4.9-NOTCHING-

It is a periodic voltage disturbance that is caused due to momentary short circuit between two phases in a three phase converter circuit.

1.5 LITERATURE SURVEY

Today power quality is the most essential variable in both levels of transmission and distribution. It's very much essential to take care of the acceptable limits of power quality. **N.G hingorani** [1], 1995, has given the basic concept of custom power. It gives the reliability of power flow. Solid state circuit breakers, static compensators, static condensers provide the basis of the custom power.

Chellali Benachaiba et al. [2], 2008, describes DVR, a compelling custom power gadget for moderating voltage swell and sag. Also gave the method of voltage restoration at the PCC i.e. the point of common coupling, DVR principles and also described about the different methods of voltage injection. DVR can handle both unbalanced and balanced situations effectively.

Mehmet Ucar et al. [3], 2008, proposed the p-q theory which is also called instantaneous reactive power theory, another control calculation has been suggested for three-phase four-wire and four-leg parallel active power filter (APF), based on this proposal, for remuneration of reactive power, harmonic currents suppressions, and balancing of the load currents under non-perfect mains voltage conditions and unbalanced non-linear load.

Kamran and Habetler [4],1998,has proposed a new method taking into account the deadbeat control, that treats UPQC inverter association as a solitary unit. The whole concept has been exhibited utilizing a 3-phase series-shunt active filter. It also uses a full-order predictive state observer. Modelling the system as a solitary multi-input, multi-output framework has many advantages. It showed faster dynamic response and steady state precision and thereby giving enhanced control execution over the independently controlled converters.

K.H Kwan et al. [5], 2007, propose a model predictive control design for the UPQC. Use of kalman filters makes it easy for the extraction of principal and harmonic parts of the given load current and the supplied voltage. The model predictive controller had been designed based on the state space model of the UPQC. The MPC controller proved beneficial in regulating the error in supplied voltage and the load current thereby regulating both supply voltage and load current. It is helpful in mitigating load variation, sag and swell.

Bhim Singh et al. [6], 2011, proposed a control method for the DVR i.e. dynamic voltage restorer in order to overcome the problems in the quality of power and regulate the terminal voltage. For regulation of dc bus voltage of the DVR and the terminal voltage proportional integral (PI) controllers are used. Synchronous reference frame hypothesis is likewise utilized for the extraction of fundamental component of the terminal voltage.

V.Khadkikar et al. [7], 2004, introduced a control procedure for UPQC. The control methodology depends on UVTG (unit vector template generation). Voltage harmonics present in the utility voltage. Steady state analysis and mathematical analysis of UPQC is given. Parallel APF maintains the overall power balance in the entire network. The current harmonics and input voltage harmonics can be repaid proficiently by the proposed control system.

Yash Pal et al. [8], 2011, present a control methodology for a 3-phase 4-wire UPQC. A 3-phase, 4 leg Voltage source inverter is used for parallel APF and a 3-phase, 3 legs Voltage source inverter for realisation of the series active power filter. Unit vector template control system is utilized for controlling the series APF, while Icosϕ control is utilized for controlling the parallel active power filter. These technique guarantees, alleviation of voltage and current harmonics, load balancing, voltage swell and droop and voltage plunges. This method helps effectively in reduction of computational time and number of sensors.

S.P Das et al. [9], 2007, proposed two control scheme models for UPQC. These two control schemes are based on the type of voltage compensation strategy; they are UPQC-Q and UPQC-P. The adequacy of the two control plans is tested. UPQC-Q can effectively share the VAR between the two compensators but not effective in controlling the unbalanced voltage sag. UPQC-P can relieve the supply voltage-unbalancing issue likewise next to controlling the voltage droop and swell.

Ambrish Chandra and Vinod Khadkikar[10],2008, suggested a method as power angle control (PAC) of UPQC so that series inverter of UPQC is used to it most extreme limit. By this PAC concept by controlling the power angle between the source and load voltages properly, both parallel and series inverters can properly share the load reactive power. This proved helpful for reduction of the parallel inverter rating of the UPQC.

1.6 MOTIVATION

Various control algorithms has been developed for controlling the voltage and current harmonics developing in the power system which has proved to be very much essential. Several methods are there which are little complicated but the methods described here requires less number of measurements and hence it’s little simple which has become the motivation for the project.

1.7 OBJECTIVES

- Study of the UPQC model.
- Improvement of the current and voltage remuneration abilities of the 3-Phase 3 Wire system using UPQC.
- Analysis and study of UVTG and synchronous reference frame and PQ theory.

1.8 ORGANIZATION OF THE THESIS

The whole thesis is sorted out in five chapters. The description in each part will be as for the following:

Chapter 1 gives an overview of power quality including the definition of power quality, the need for a better quality of power, Common disturbances in power system, literature survey, motivation of the project and objective of the project. It also includes the organisation of the thesis.

Chapter 2 describes the various methods to mitigate the problem in power quality, a brief description of unified power quality conditioner and the classification of UPQC into various groups.

Chapter 3 clarifies about the control algorithm used for the UPQC that includes both UVTG and synchronous reference frame control. The generation of reference signals for both series and shunt inverter has been explained here.

Chapter 4 is furnished with the MATLAB simulation results and description of both the methods and demonstrates the adequacy of proposed method to alleviate the force quality problems.

Chapter 5 presents the conclusion took after by the references.

CHAPTER 2

VARIOUS METHODS TO MITIGATE POWER QUALITY PROBLEM

In today's distribution system power electronics based gadgets have gotten to be the most essential part. They have a numerous advantages but on the other hand they also show many lacunas. They draw harmonic current along with the fundamental power frequency which contaminates the distribution system. Keeping in mind the end goal to give specialized answers for the new difficulties forced on distribution system, the idea flexible AC transmission systems (FACTS) has been incorporated. These FACTS devices use to upgrade the controllability and to build power exchange ability of the transmission framework. Two methodologies are there for the control of reactive and active power one utilizes traditional thyristor switched capacitors (TSC) and thyristor switched reactors (TSR), and alternate uses self-commutated Switching converters. Both the plans help to productively regulate the real and reactive power, yet as it were the second one can be utilized to remunerate current and voltage harmonics. In addition, self-commutated switching converters introduce a superior response time and more remuneration adaptability.

2.1 STATIC VAR COMPENSATOR

Various types of compensators are used that includes SVC, TSC, TCR, STATCOM etc. Static VAR compensators (SVC) control the AC voltage by creation and absorption of reactive power by the passive elements like resistor and capacitor. SVC mainly contains anti parallel thyristors along with the passive elements. If its thyristor switched capacitor then the passive element is capacitor and reactor in case of thyristor controlled reactor. The main problem with the utilization of SVC is that the reactive power took care of by the SVC is restricted by the passive element size.

2.2 STATCOM

STATCOM is one of the standout FACT devices amongst all the FACTS devices. It may contain a voltage source converter or a current source converter and provides a better response. It helps in maintaining a good voltage profile and improves the stability. If we are using this in the distribution system then it can be referred as D-STATCOM i.e. the distribution STATCOM. It mainly consists of an inverter circuit, inductor, a capacitor acting as DC source, control circuit for reference current generation. D-STATCOM helps in compensation of the load harmonic as it acts as a current source. In addition to this it as many more advantages like source current balancing, suppression of DC offset in the load and it helps the load to work at power factor of unity.

2.3 DYNAMIC VOLTAGE RESTORER

Dynamic voltage restorer (DVR) provides series compensation. It consists of a voltage source inverter in series with the supply line that helps in achievement of a particular load voltage. At the point when an outside DC voltage source is used for VSI, the DVR can be utilized for compensation of voltage harmonics, management of load voltage, and to remunerate voltage imbalance.

2.4 ACTIVE POWER FILTER

Active power filters are also widely used is they provide a great answer for tackling the power quality issues in the distribution system. These AF includes parallel active power filter, series active power filter and also the combination of the above two i.e. termed as the hybrid active power filter. Series active power filter mainly helps for mitigation of harmonics in the voltage whereas shunt active power filter mainly deals with the compensation of harmonics in the load current.

2.5 UPQC

In the context of up gradation of quality of power UPQC plays a very vital role. It provides blessings of parallel and series active power filter both. Being a multitasking power conditioner UPQC can be utilised for compensation of numerous voltage disturbances, voltage flicker and it also provides prevention to the harmonics in the load current and doesn’t allow them to enter into the power system and contaminate the quality of power. This custom power equipment has the ability of mitigation of the problems affecting the working of sensitive equipment or loads. UPQC provides compensation to harmonics in current (shunt part) as well as that to the voltage (series part), controls the flow of power and also overcomes the disturbances in voltage like voltage swell, sag etc. The essential parts of unified power quality conditioner are shunt inverter, series inverter, Dc link capacitor, Shunt coupling inductor and series transformer.

2.5.1 UPQC CONFIGURATION

UPQC mainly consists of following parts-

Shunt inverter: A shunt connected voltage source inverter acts as shunt inverter. It is helpful in cancellation of current distortions i.e. compensates the harmonic current of the load. It also provides assistance in keeping up a steady value for the DC link capacitor voltage and also helps in improvement of system power factor. Furthermore it is also helpful in compensation of load reactive current. Usually hysteresis band controller is employed for controlling of the shunt inverter output current. By adjusting the semiconductor switches reference current can be made to follow the output current and stays within the particular hysteresis band.

Series inverter: It is a series connected VSI (voltage-source inverter) acting as a source of voltage. Its connection is in series with the line by using a series transformer. It helps in overcoming the voltage based distortions. It helps in maintaining a sinusoidal load voltage by eliminating the load voltage imbalances and the flickers in the terminal voltage. PWM techniques are used for controlling the series inverter. Mostly hysteresis band technique of pulse width modulation is used. There are many advantages of using this PWM technique. It provides a better and faster response speed, easy to implement and it can work properly even without having the knowledge about the parameters of the system.

DC link capacitor: It is used for back to back connection of the series and shunt VSIs. The DC voltage developed across the capacitor acts as a constant voltage and helps in proper operation of both shunt and series inverters. If regulated properly the voltage provided by this capacitor can be used a source for both active and reactive power and the use of any outer DC source e.g. battery etc. can be eliminated.

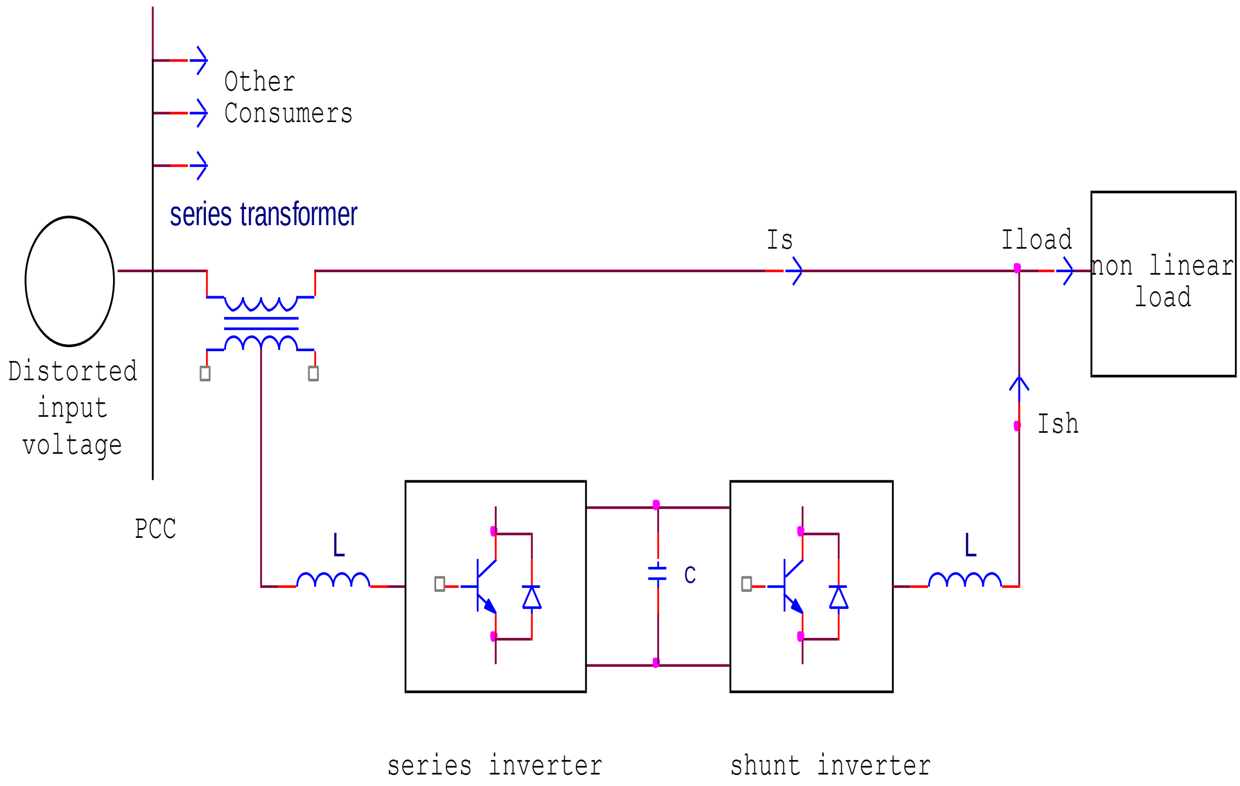


Figure 2.1 Basic block diagram of UPQC

Shunt coupling inductor: It is helpful in interfacing of the shunt inverter to the network. The main benefit of this is to smoothen the wave shape of the current by elimination of the ripples produced in the current.

LC filter: It is present near the series inerter output of UPQC. Acting as a low-pass filter (LPF), it is helpful in attenuation of high-frequency voltage components of the output voltage of the series inverter.

Series transformer: The series inverter generates a voltage for maintenance of load voltage sinusoidal at a particular required value. Series inverter helps in injection of this voltage through the series transformer. It is required to maintain a particular turn’s ratio in order to maintain a low current flow through the series inverter.

2.5.2 UPQC-CLASSIFICATION

There are many criteria for classifying the UPQC. The main criteria of classification can be divided broadly into two groups. The first one is classifying them on the basis of their structure which is seen physically and the other based on the method in which they compensate the sag in the load voltage. These two methods can further be subdivided into various groups. The one that depends on the physical structure can be again divided based on the type of converter used, type of supply whether three phase or single phase and the last one is in the basis of UPQC configuration. The various classes of UPQC have been described below.

2.5.2.1- ON THE BASIS OF PHYSICAL STRUCTURE

On the basis of physical structure it can be further subdivided into three groups as given below

(a) BASED TOPOLOGY OF THE CONVERTER

Converter used can be either-

- VSI-Shares a common DC link capacitor. This is used commonly as losses are low losses, low price and it can be utilized in case of multi-level inverter also.
- CSI-Uses an inductor to form the DC link. This is not used commonly as it results in high losses, high price and it's not possible to incorporate them as we go for multi-level inverter.

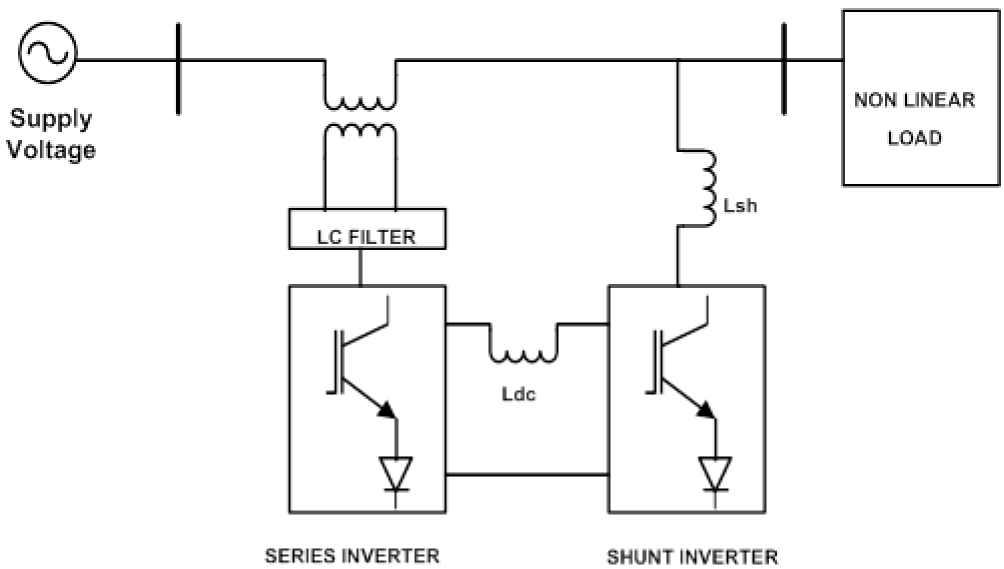


Figure 2.2 CSI based UPQC

(b) ON THE BASIS OF SUPPLY SYSTEM:

It can either use a single phase supply or a three phase supply.

(i) SINGLE PHASE-

- 2H bridge- It has a total of eight switches and it's the most familiar configuration.
- 3leg topology- It has 6 switches in total. It can be used for the operations demanding less cost and power.
- Half bridge- It uses the minimum number of switches i.e. 4 switches. The reduction in the number of switches also has an impact on the level of compensation.

(ii) THREE PHASE-

- Three wire - it is the one that is most commonly used. It can be used in arc welding, frequency converter etc.

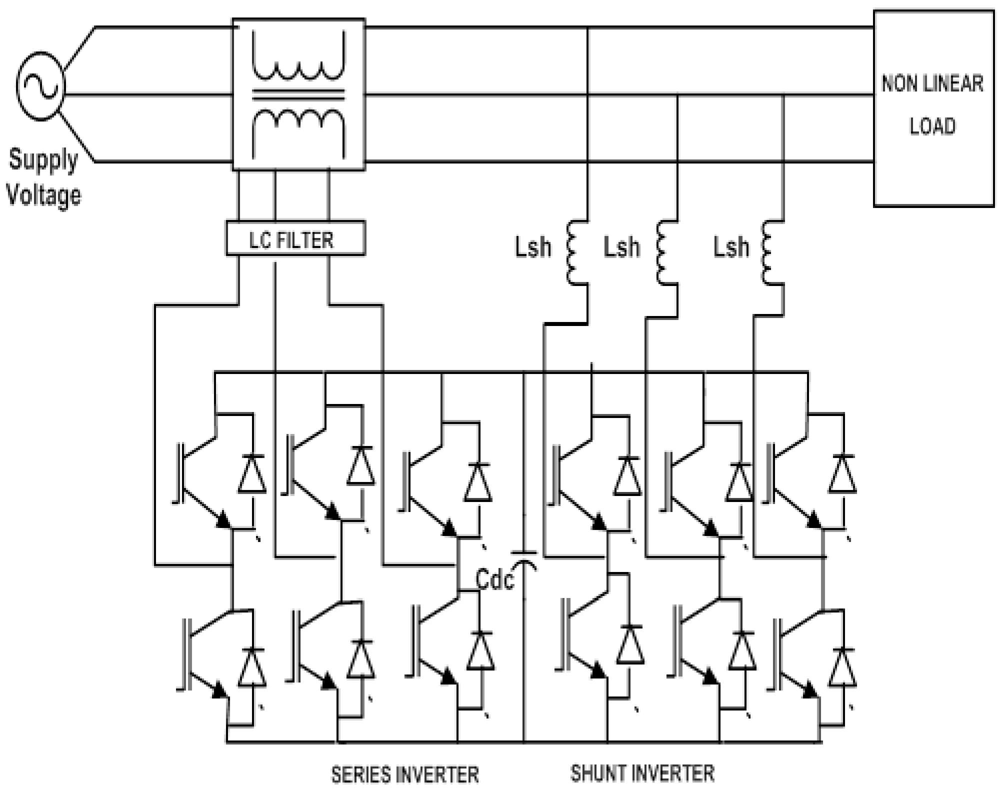


Figure 2.3 Three phase UPQC

- 3 phase 4 wire - It is widely used in the industrial applications. Because of the extra neutral wire present it needs a higher and better degree of compensation. It can be of various types like two capacitor, three half bridge inverter and four inductor configuration. In two capacitor configuration two split capacitor acts as DC link and in four inductor configuration additional 4th leg of shunt inverter helps in load neutral current compensation.

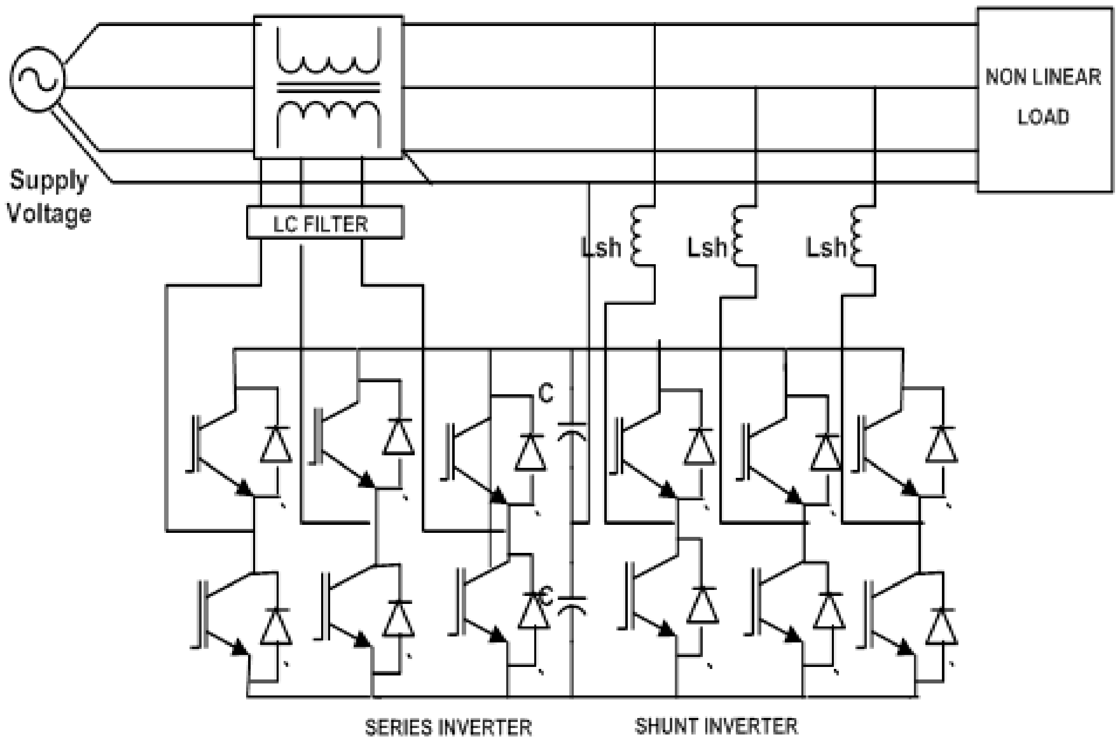


Figure 2.4 Three phase four wire UPQC

(c) ON THE BASIS OF UPQC CONFIGURATION

On the basis of UPQC configuration mainly there are five types of UPQC as described below-

- **Right and Left Shunt UPQC:** It is based on the position of parallel converter as compared to the series converter. If the shunt converter is laced on the right hand side of the series converter then it is termed as UPQC-R and if it is laced on the left hand side then it is termed as UPQC-L. UPQC-R is the one that is most commonly used. It shows improved performance in comparison to that of the UPQC-L. UPQC-L can be utilized for some articular cases.

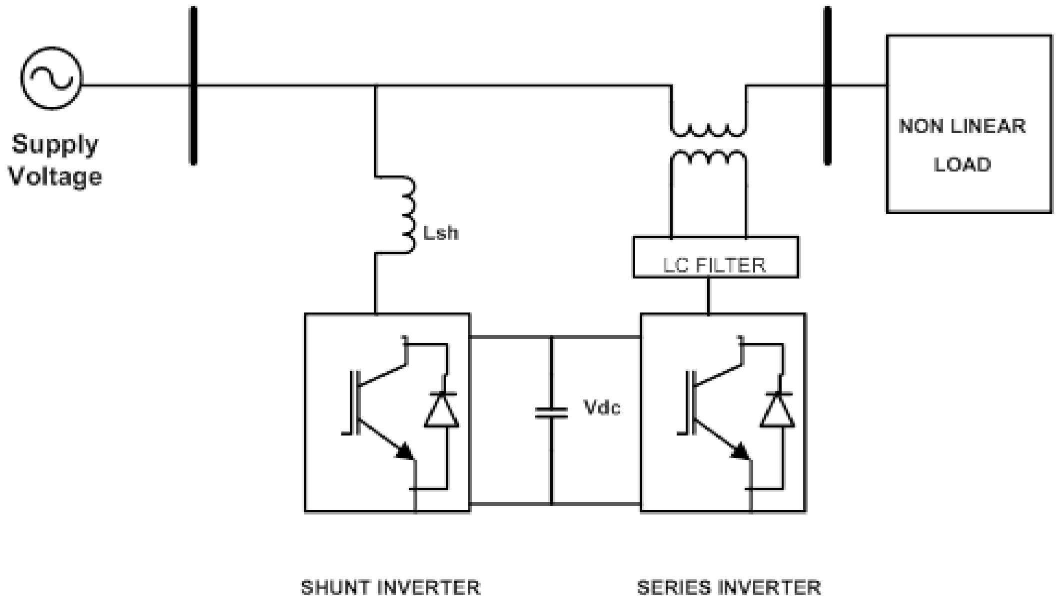


Figure 2.5 UPQC-L

- **Interline UPQC:** Here both the inverters of UPQC i.e. series and shunt inverters are used in between two distribution feeders. The connection of one UPQC is in series with the first feeder and the second is in parallel with the second feeder. In this way both the feeders gets the advantage of effective control of the voltage. But it also shows some problems and hence used only for certain particular cases.

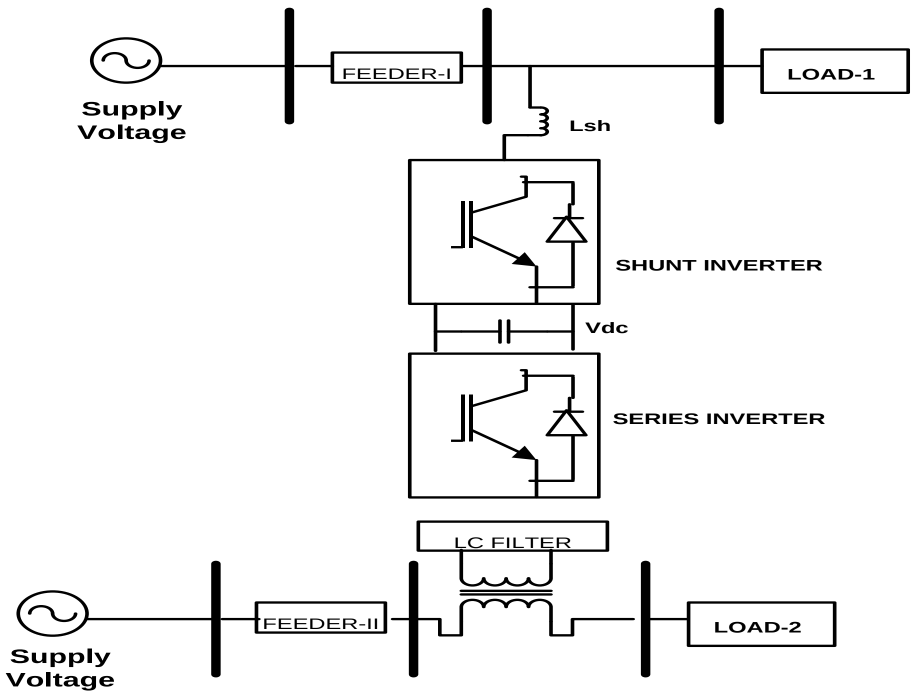


Figure 2.6 Interline UPQC

- **Modular UPQC:** It is the connection of several H-bridge inverter modules. The shunt part has series connected H-bridge inverter modules with that of the transformer and series part connection is in directly in series and doesn't need a series transformer for connection with the distribution transformer.

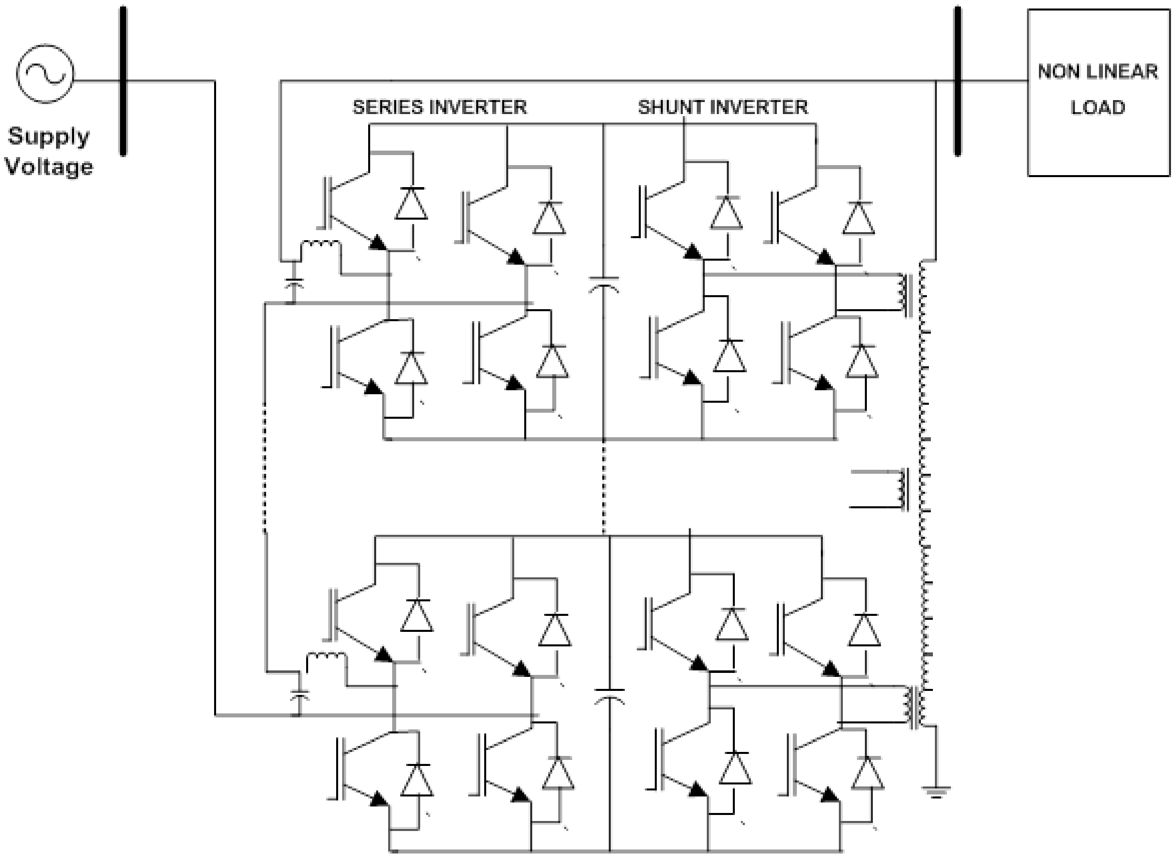


Figure 2.7 Modular UPQC

- **Multilevel UPQC:** Used for getting higher power level. It can be of various levels as per the requirement. Various levels of MLI that are usually realised are three, five, seven etc. As the number of level increases the power level increases but it has a disadvantage too. With the increase in the number of levels the harmonic content also increases.

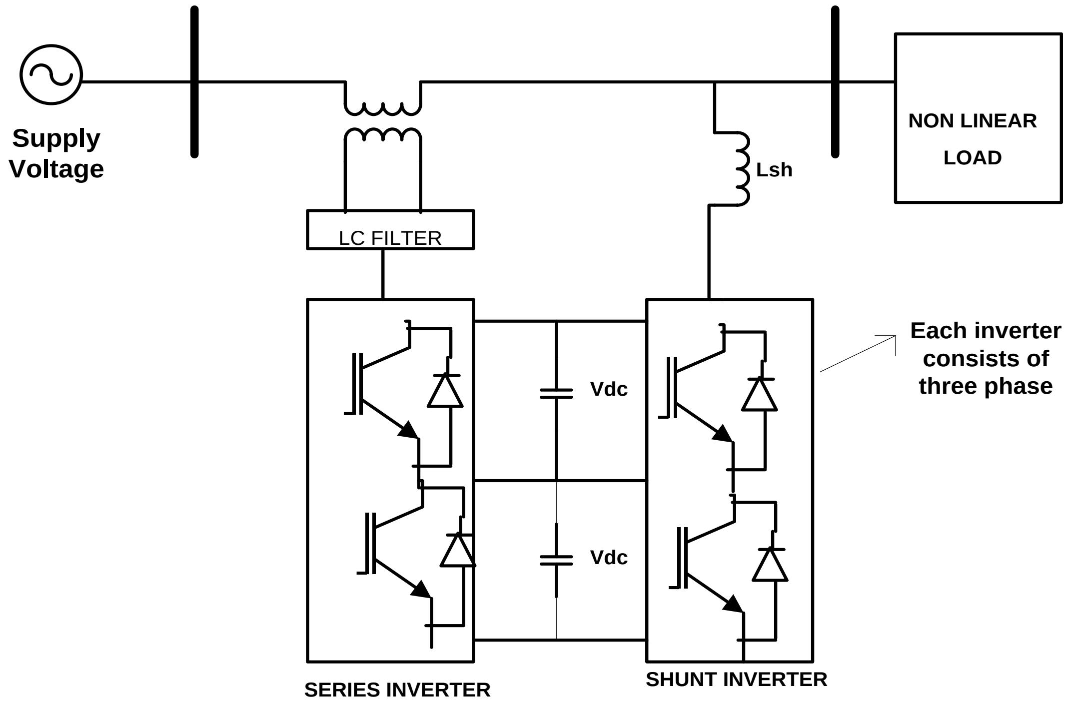


Figure 2.8 Multilevel UPQC

- **Multi-converter UPQC:** Here three inverters are used. Third inverter is used in order to assist the dc capacitor voltage. There are various ways for the connection of the third inverter.

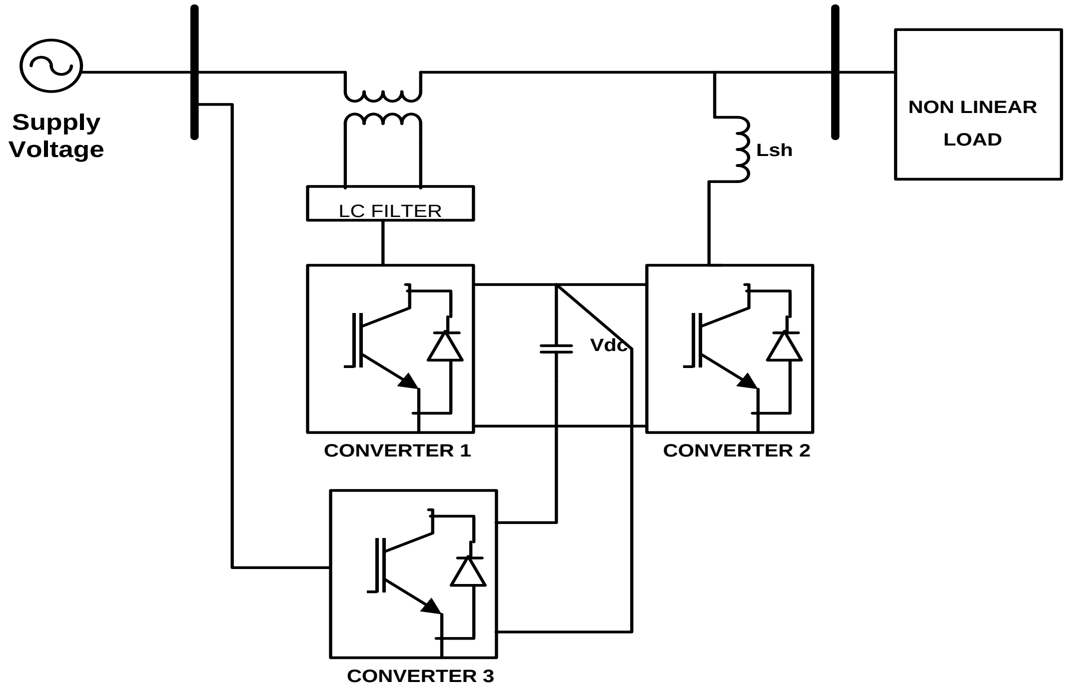


Figure 2.9 Multi-converter UPQC

2.5.2.2 BASED ON VOLTAGE SAG COMPENSATION

- **UPQC-P:** It is an active power control UPQC where use of active power is done for mitigation of voltage sag. Here injection of a voltage component is done in series with the ac line. The voltage component that is injected into the system is equal to the difference between the load and the existing voltage.
- **UPQC-Q:** It is a reactive power control UPQC, where the use of reactive power is done for mitigation of voltage sag. The main principle here is the injection of a quadrature voltage. But the disadvantage of UPQC-Q is that it increases the rating of series inverter.
- **UPQC-VAminm:** It is minimum volt ampere loading UPQC. It is used to minimize the volt ampere loading during the compensation. In this case the injection of voltage is done in a certain angle in regards to the current.
- **UPQC-S:** It gives simultaneous active and reactive power control. In this system series inverter can be effectively utilized. Its control is little difficult and hence it is used widely if the control is digital.

CHAPTER 3

CONTROL TECHNIQUE FOR UPQC

Various control techniques have been used for the control of harmonics in voltage and current by using UPQC. Here mainly two methodology has been described i.e. the unit vector template generation technique and the Synchronous reference frame and PQ theory.-

3.1 UNIT VECTOR TEMPLATE GNERATION

The control technique used here is Unit vector template generation technique In this case supply voltage is made distorted and Unit Vector Templates are extracted from it. The distorted input source voltage contains harmonic components in addition to the fundamental component. For extraction of these unit vectors**,** the supply voltage is first measured and the product of this and gain (1/ Vm) is done, Vm being the peak fundamental supply voltage. After this unit vector templates are generated by using a phase locked loop.

Va = Sinωt

Vb = Sin (ωt-120)

Vc= Sin (ωt+120)

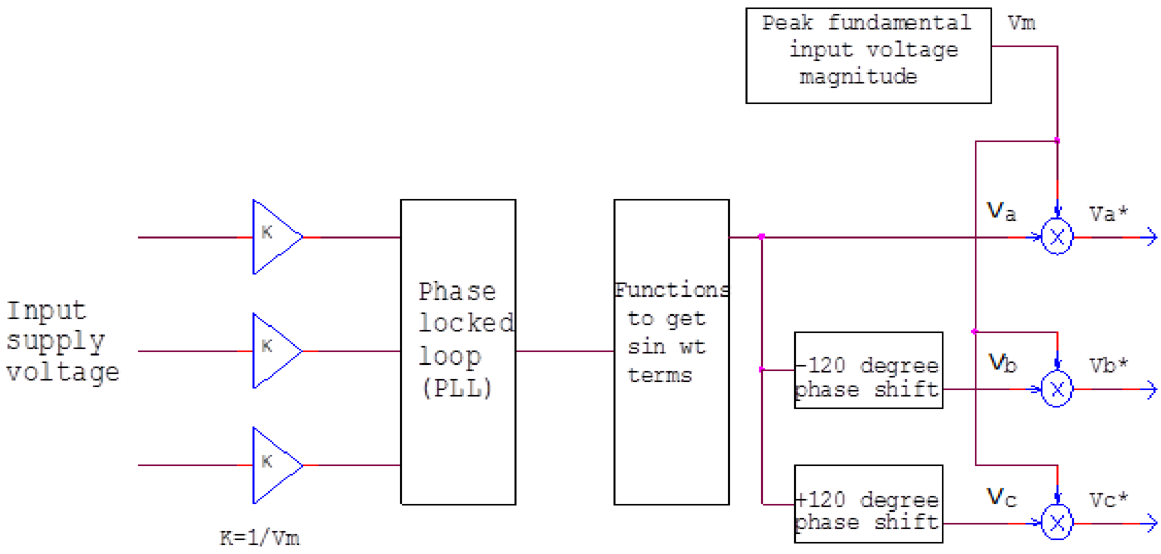


Figure 3.1 Generation of Unit Vector Templates and reference Load Voltages

Supply voltage is then multiplied with the unit vector templates and reference load voltage is generated. The reference load voltage generated is given by V*abc.

$V^{*}abc = Vm*Uabc$

Then the comparison of actual load voltage and reference load voltage is done. Error is calculated and send into a hysteresis band for generating the gate pulse for the series inverter. Shunt Active Power Filter is used for current harmonics compensation. Generation of pulses for the shunt inverter DC link voltage is then measured an it its comparison is done with the reference dc link voltage. After that error is processed by utilizing a PI controller, and to produce the reference current these results are multiplied by unit vector templates. Comparison of reference and actual source current is done and a hysteresis band controller is used for processing the error and production of gate pulses for parallel inerter circuit is completed.

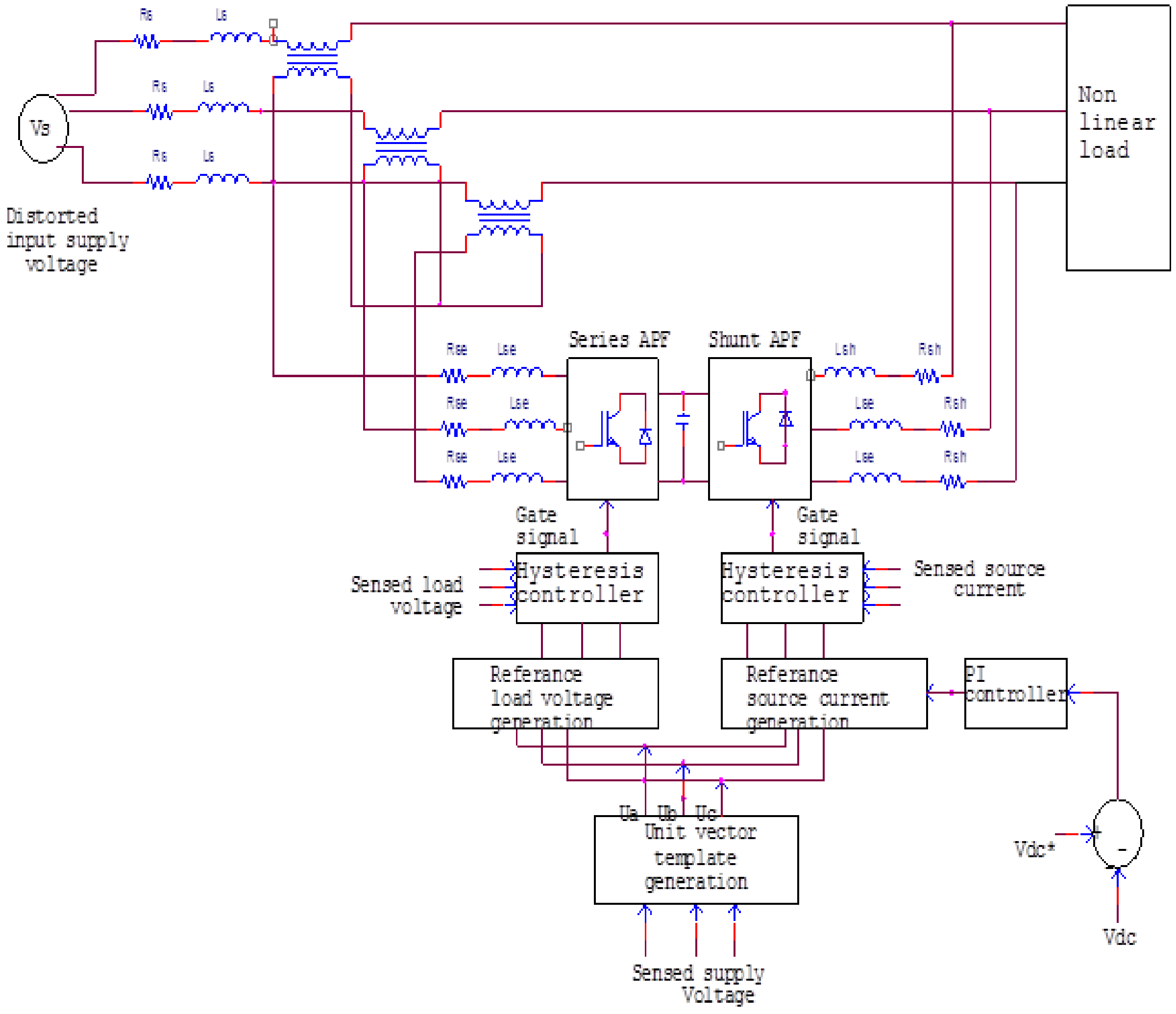


Figure 3.2 Overall Control Circuit Configuration of UPQC

3.2 SYNCHRONOUS REFERENCE FRAME AND P-Q CONTROL OF UPQC-

3.2.1-Control Method for Series Active Filter

For controlling the source side voltage aggravation SAF is utilized. In this method, the reference voltage that needs to be infused by the series transformers is ascertained by comparison of the positive – sequence component of the source voltage with that of the source voltage. The reference generation calculation for SAF is demonstrated as follows-

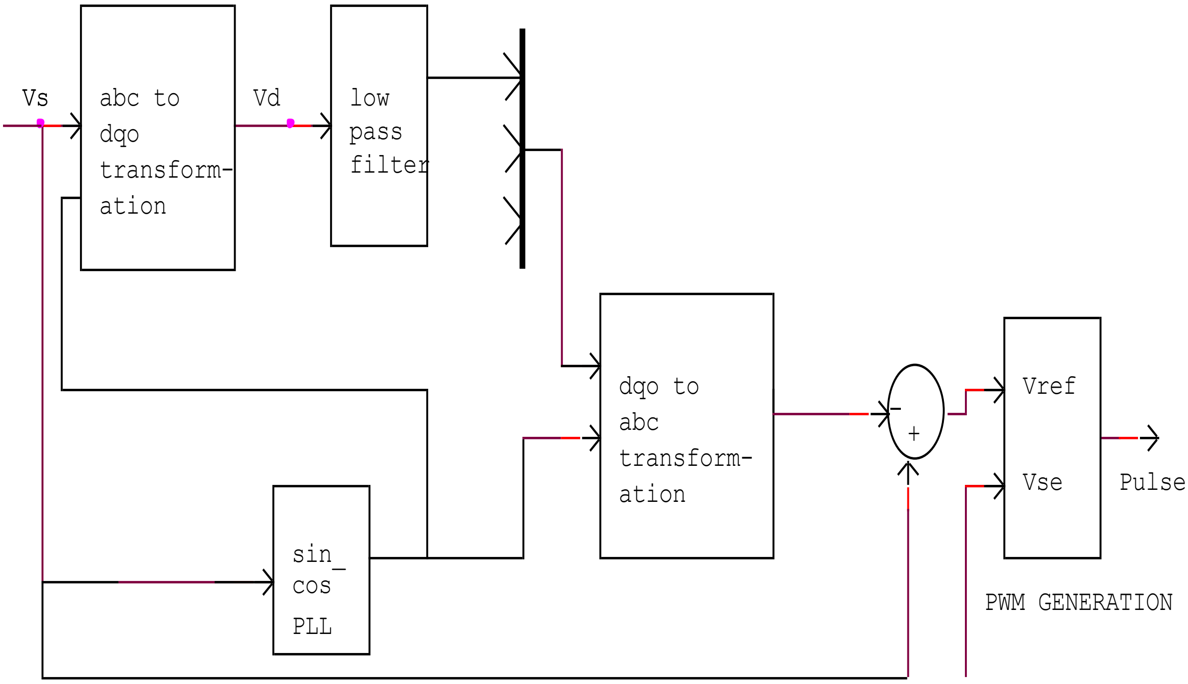


Figure 3.3 Control algorithm of SAF

Equation depicting transformation of supply voltage and load current into d-q-o coordinate are given below -

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad \text{...... (1)}$$

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} \quad \text{....... (2)}$$

Along with the fundamental component harmonics are also present in the d-axes voltage. A second order LPF is used for filtering out the harmonic components. Then the reference voltage Vref is then estimated by utilizing d-q-o to a-b-c transformation. Then the output of series active filter and the reference voltage generated is fed to a hysteresis band controller to generate the gate pulses.

3.2.2-Control Method Employed for Shunt Active Filter-

For calculating the reference current in this method P-Q methodology has been utilized. Clarke's transformation given in equation (1),(2),(3) and (4) are used for transformation of reference voltages generated at SAF and load current in to α-β-0 coordinates –

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \quad \text{.......} \ (3)$$

$$\begin{bmatrix} Id \\ Iq \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad \text{.......} \ (4)$$

Equation (5) is used for the calculation of real power and imaginary power in the Source side. These are instantaneous power-

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ -V\beta & V\alpha \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad \text{.......} \ (5)$$

For compensating reactive power and the harmonic component, real power is taken as the reference and the source current reference can be calculated by Eq.(6).

$$\begin{bmatrix} Is\alpha * \\ Is\beta * \end{bmatrix} = \frac{1}{V\alpha^2 + V\beta^2} \begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix} \begin{bmatrix} P + \Delta P \\ 0 \end{bmatrix} \quad \text{.......} \ (6)$$

Where $\Delta P = Po + Ploss$

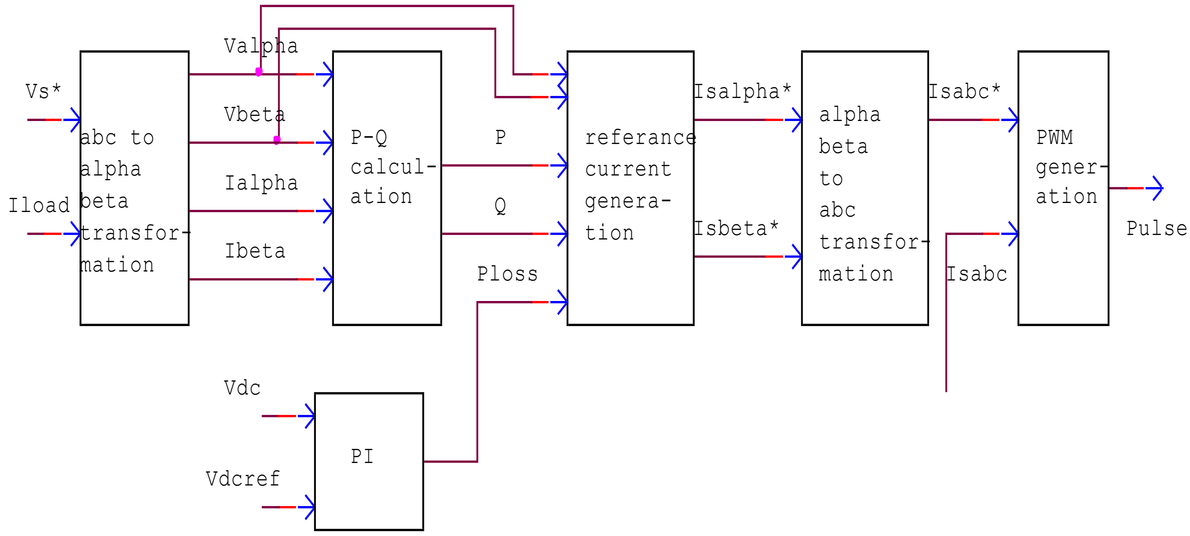


Figure 3.4 Control algorithm of PAF

Due to the absence of unbalance the power Po is zero. Comparison of measured and reference DC-link voltage is done and a Proportional integral controller is used for processing the error produced. The main reason behind using this controller is that it helps in reducing the steady state error to a zero value. PI controller's yield is termed as Ploss. Then the reference source current is converted to a-b-c frame of reference using the Eq.(7)-

$$\begin{bmatrix} Isa * \\ Isb * \\ Isc * \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Is\alpha * \\ Is\beta * \end{bmatrix} \quad \text{...... (7)}$$

Finally the comparison of these current and actual source current is done by the help of a hysteresis band controller and gate pulses for the shunt Active power filter are generated.

CHAPTER 4

SIMULATION RESULTS AND DISCUSSION

Simulation results for both the methods i.e. unit vector template generation technique and synchronous reference frame and PQ method has been given here.

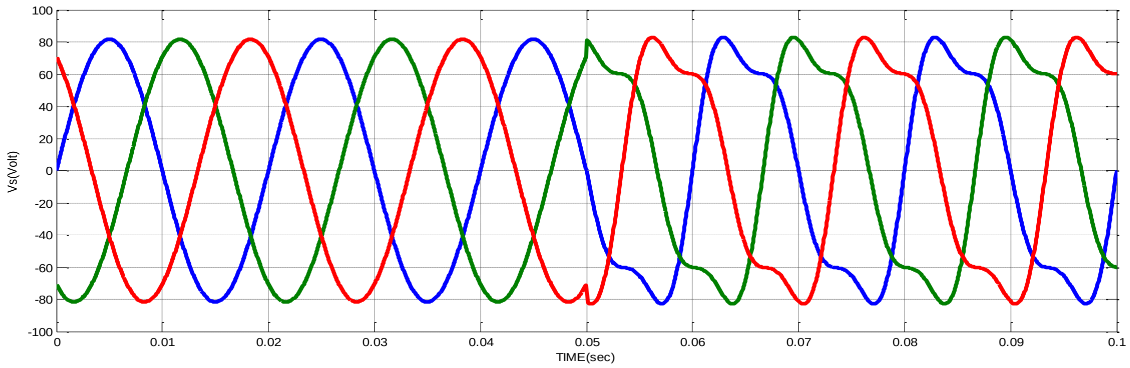
4.1 UNIT VECTOR TEMPLATE GENERATION TECHNIQUE

Ratings of various parameters of UPQC:

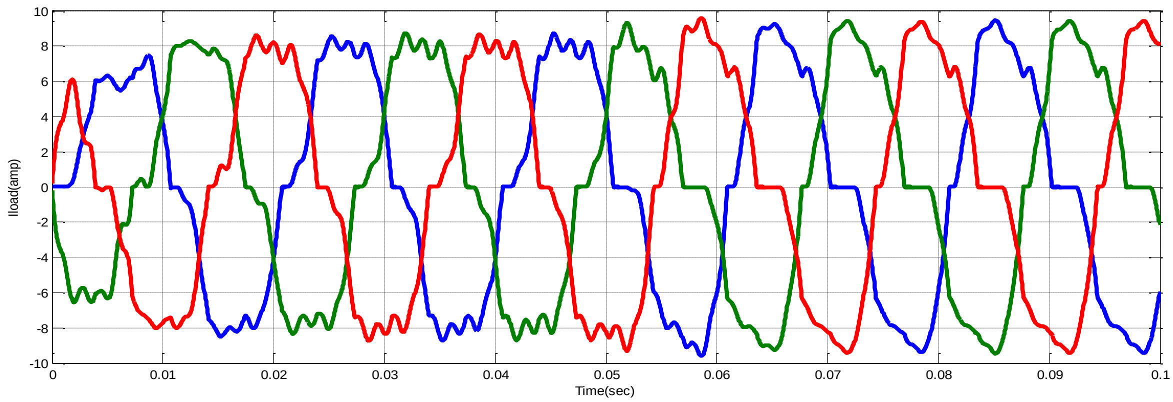
Source side:	Supply Voltage = 100V
	Frequency = 50 Hz
Load side:	Diode bridge rectifier with R-L load that acts as a Non-linear load
	R_{Load}=10Ω and L_{Load}=5mH.
Series active power filter:	R_S=0.1 Ω; L_S=3 mH; C_S= 30µF
Shunt active power filter:	L_{Sh} = 20 mH; and R_{Sh} = 0.3Ω;
DC Link Capacitor	C=600µF
PI Controller:	K_p= 0.05; and K_I= 35;

RESULTS

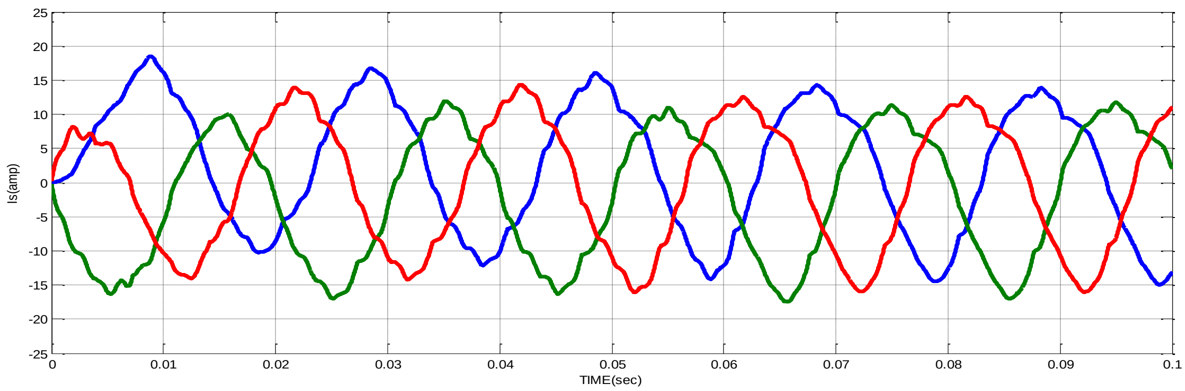
Here harmonics have been injected to the system at 0.05sec.



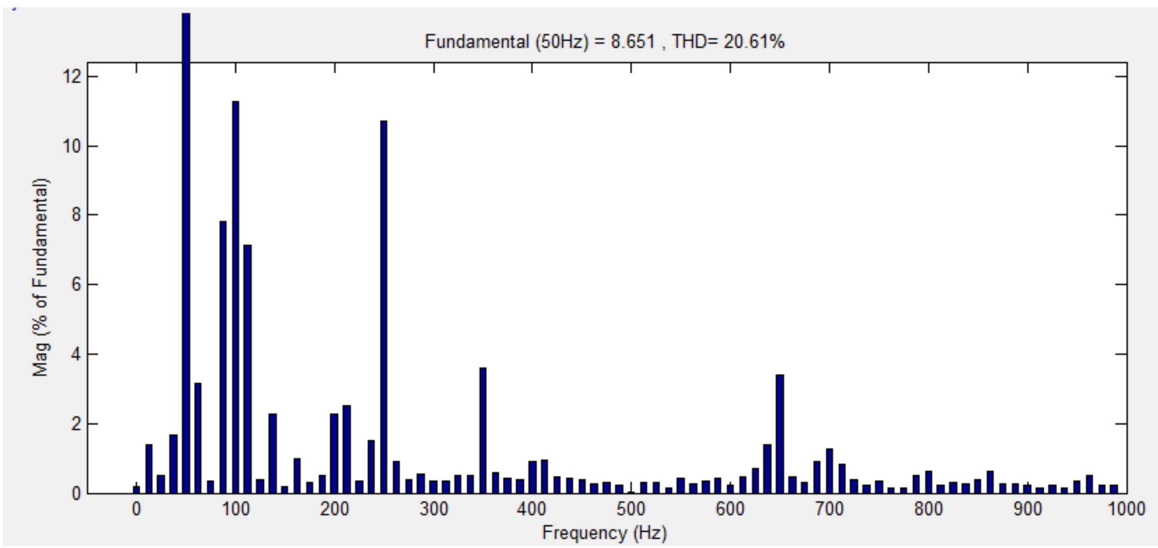
(a)- Source voltage



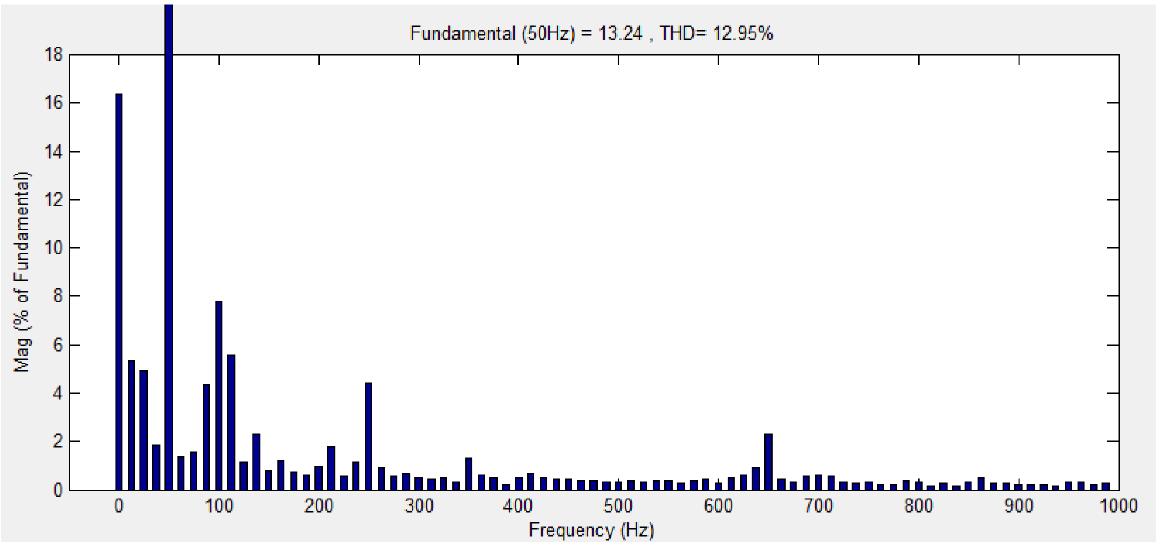
(b) Load current



(c) Source current after compensation



(d)FFT analysis of Load current



(e)FFT analysis of Source current

Figure 4.1 Simulation results for UVTG

From the results it can be inferred that

- The harmonics in the current can be reduced by using this method and the harmonics in Source current is low than that of the Load current.
- After compensation, THD in source current is low i.e. 12.95% as compared to that of the load current i.e.20.61%.

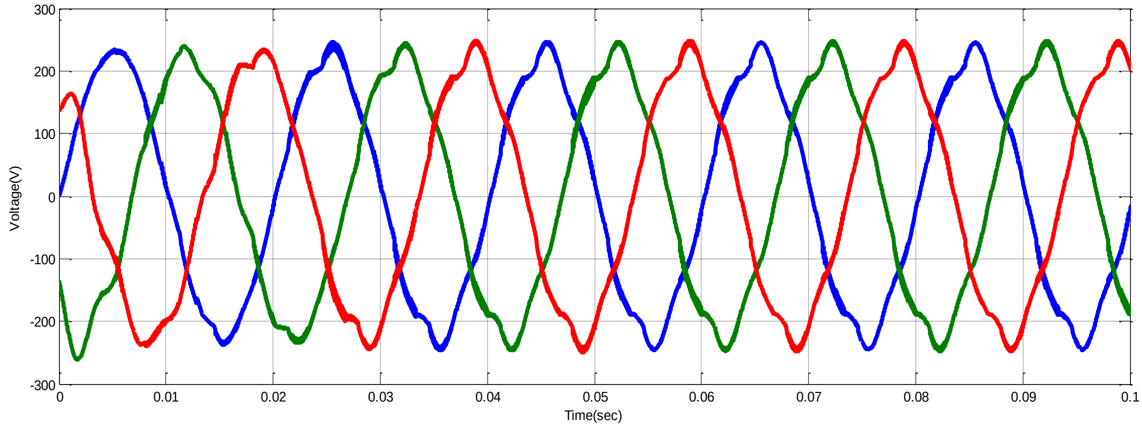
4.2 SYNCHRONOUS REFERENCE FRAME AND P-Q CONTROL TECHNIQUE

Ratings of various parameters of UPQC:

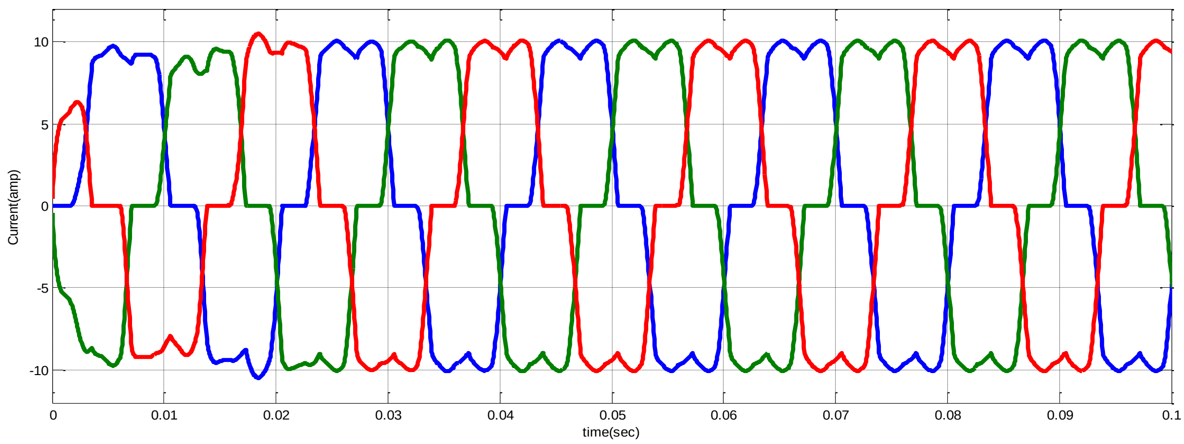
Source side:	Supply Voltage = 326V
	Frequency = 50 Hz
Load side:	Diode bridge rectifier with R-L load that acts as a Non-linear load
	R_{Load}=30Ω and L_{Load}=11mH.
Series active power filter:	R_S=0.65 Ω; L_S=4 mH; C_S= 60µF
Shunt active power filter:	L_{Sh} = 2.5 mH; and R_{Sh} = 10Ω;

DC Link Capacitor C=2200µF

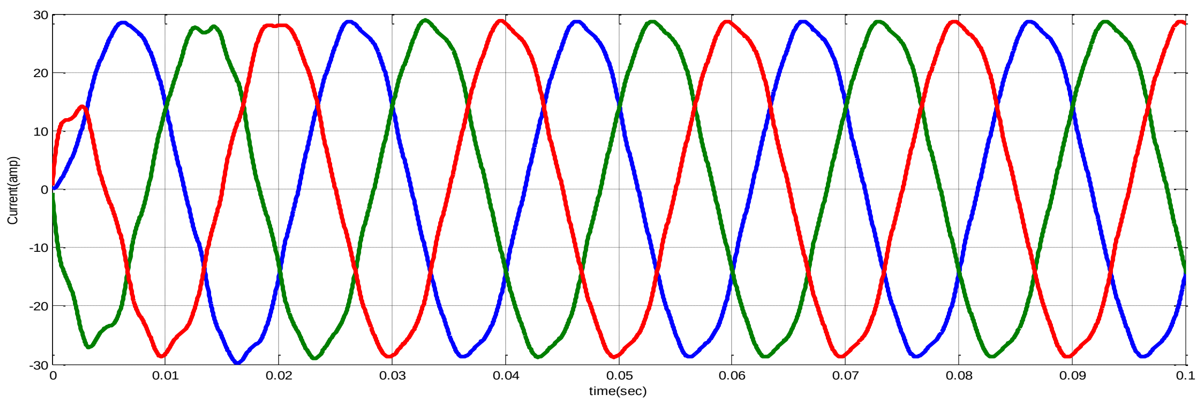
PI Controller: K_p= 0.05; and K_I= 20;



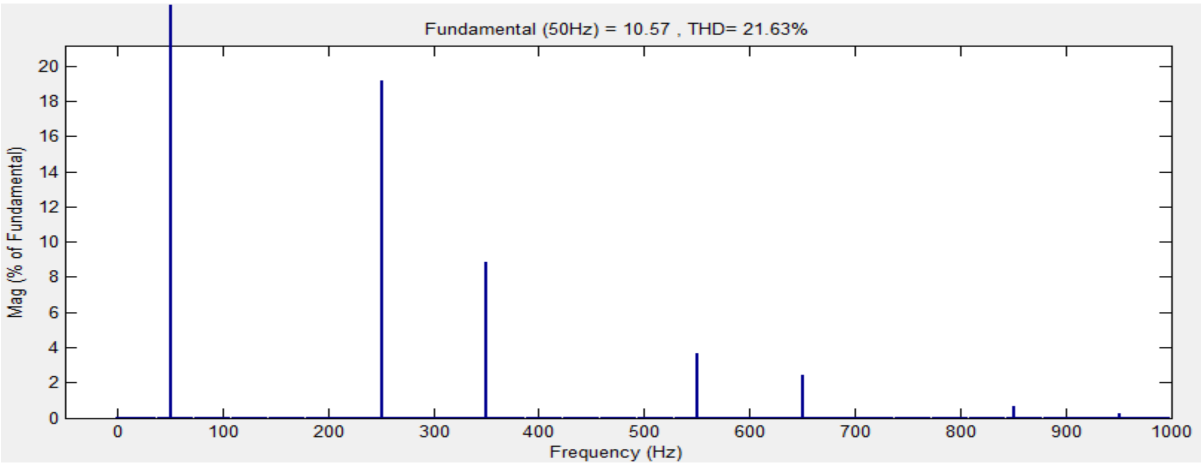
(a)- Source voltage



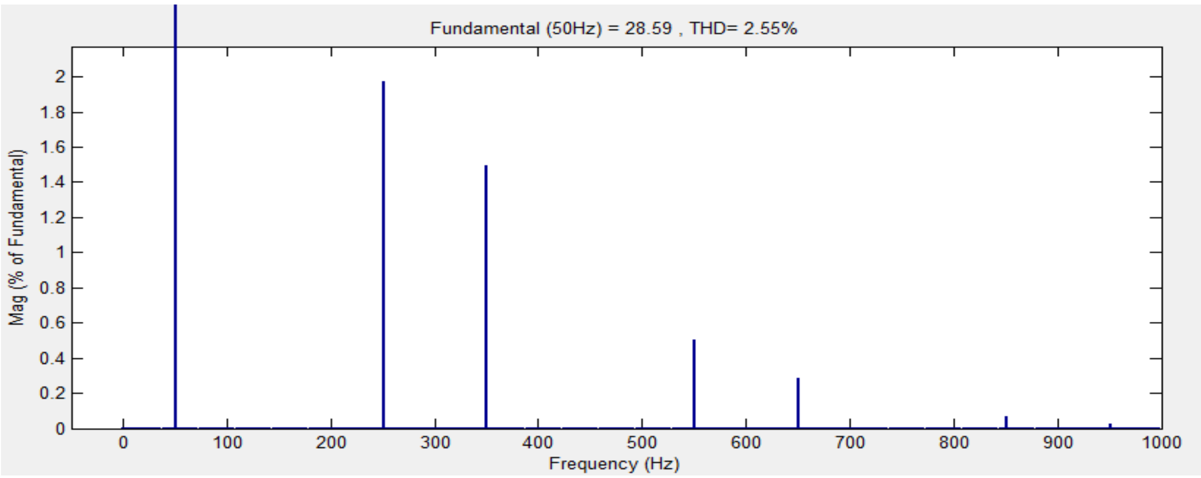
(b) Load current



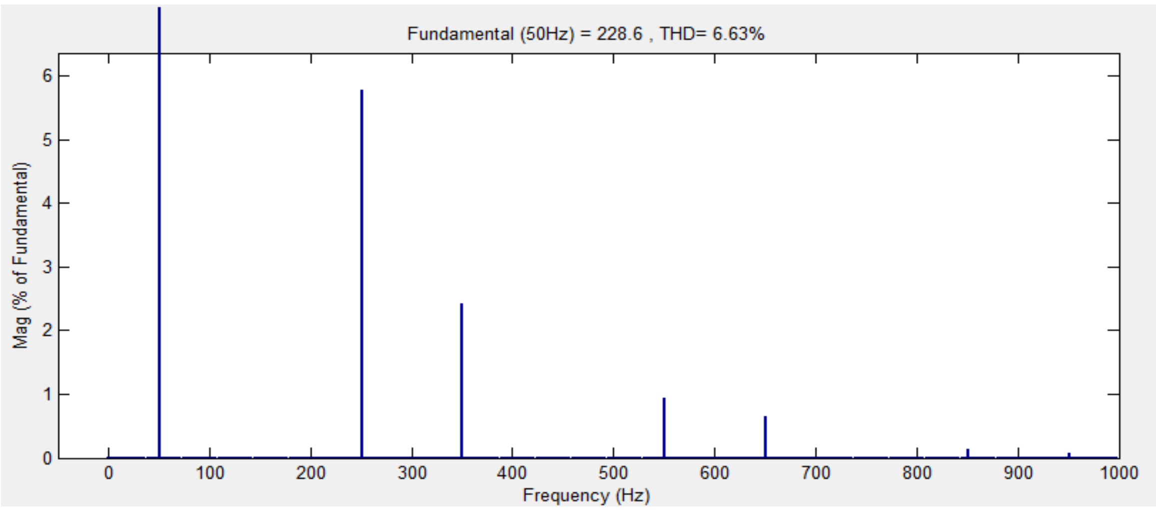
(c) Source current after compensation



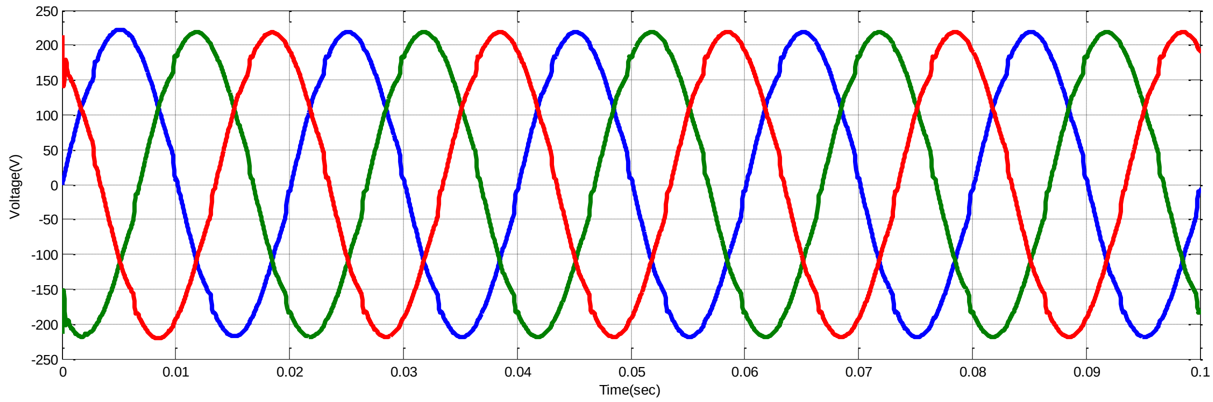
(d)FFT analysis of Load current



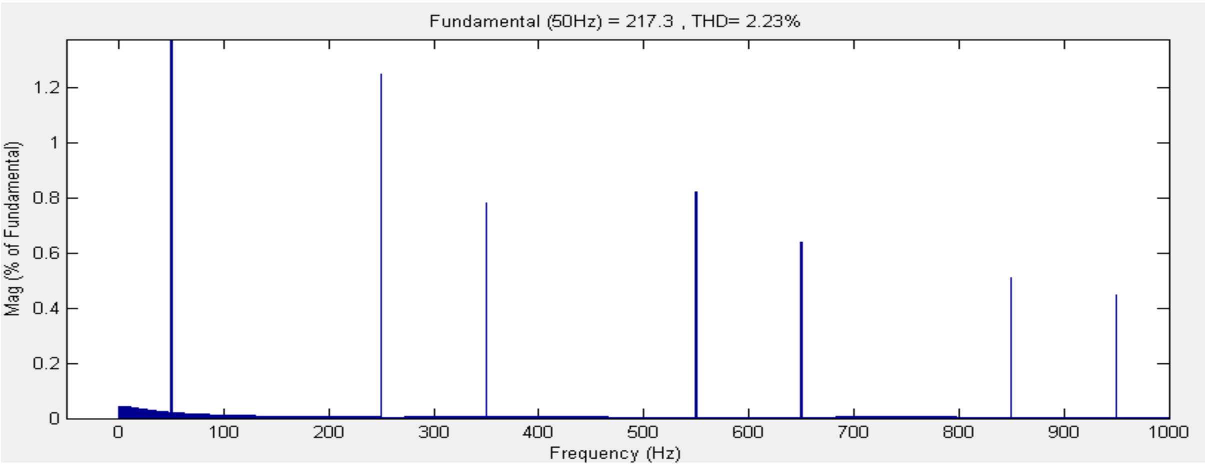
(e)FFT analysis of Source current



(f)FFT analysis of Source Voltage



(g)Load Voltage



(h)FFT analysis of Load voltage

Figure 4.2-Simulation results for Synchronous Reference Frame and p-q control technique

From the results it can be inferred that

- Harmonics in voltage and current can be efficiently reduced by this method.
- After compensation, THD in source current is low i.e. 2.55% as compared to that of the load current i.e.21.63%.
- THD of load voltage also reduces to 2.23% as compare to that of source voltage i.e. 6.63%.
- The magnitude of load voltage is lower than that of the source voltage because of the drop during the process of transmission.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

A simplified control of UPQC that is relies on generation of unit vector templates and another method based on synchronous reference frame, P-Q control technique has been given for UPQC. Both of these methodologies provides effective solution for the improvement of power quality, solving the problems related with the power quality and helps in mitigation of voltage and current harmonics. Simulation of a Simulink based model has been done. From the simulation results it can be inferred that the current harmonics that are caused by non-linear load can be compensated very effectively by using proposed synchronous reference frame control method as compared to that of the UVTG method. But on the other hand UVTG method provides a relatively simple solution towards the power quality improvement.

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